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Original Article

Assessment of Left Main Coronary Stenosis by Transesophageal Echocardiography

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Abstract

Introduction: Coronary angiography is, and remains, the gold standard for evaluating the left main coronary artery (LMCA) stenosis. Transthoracic echocardiography has been shown to be of value in demonstrating LMCA anatomy and arteriosclerotic lesions.

Aim: The purpose of the study was the utility of transesophageal echocardiography in assessing LMCA stenosis.

Methods: The study was conducted in the Department of Cardiology, Government Rajaji Hospital, Madurai. Transesophageal echocardiography was done and LMCA visualized at midesophageal transverse view at the base of the heart and the level of the left sinus of Valsalva and flow was recorded with pulsed wave Doppler.

Results: We studied 25 patients of whom 20 were male, and 5 were female. 16 patients presented as inferior wall myocardial infarction, six as anterior wall myocardial infarction, and three as stable angina. The mean size of the LMCA at the level of the ostium is 3.27 mm + 0.6 mm, shaft level is 3.7 mm + 0.74 mm, and at the level of bifurcation is 2.87 mm + 0.34 mm. The length of the LMCA was 7 mm + 1.83 mm. All patients show stenosis of the LMCA and turbulence. The diastolic flow velocity before the stenosis was 84 cm/s + 16.7 cm/s and after the level of stenosis was 343 cm/s + 43.4 cm/s. The diastolic flow velocity ratio between LMCA and LAD is 1.24%. All patients underwent quantitative coronary angiogram and showed LMCA stenosis.

Conclusion: Transesophageal Doppler assessment of coronary blood flow is a highly sensitive and specific non-invasive method in the diagnosis of stenotic and occlusive atherosclerosis of the main coronary arteries.

Key words: Coronary stenosis, Left main coronary artery, Transthoracic echo

INTRODUCTION

Quantitative evaluation of coronary stenosis is clinically important. Quantitative coronary angiography is usually performed for estimating the severity of coronary stenosis. Intracoronary blood flow velocity measurements using Doppler catheters or Doppler ultrasound guide systems have also been proposed as an alternative method for evaluating the functional severity of coronary stenosis at baseline as well as for assessing the results of interventional procedures.[1-3] Johnson *et al*. demonstrated in a canine model that the cross-sectional area (CSA) of the coronary stenosis could be calculated with a Doppler catheter using the continuity equation, which was originally introduced for measuring stenotic valve area more recently, Nakatani *et al*. showed in 13 patients with mild-to-moderate stenosis that application of the continuity equation to Doppler catheter measurement of coronary flow velocity could be used to compute the severity of coronary stenosis successfully.[4,5] These methods, however, remain invasive, requiring cardiac catheterization, and cannot be repeated without risk during serial follow-up studies. Furthermore, in a consecutive series of 52 patients undergoing percutaneous transluminal coronary angioplasty, Di Mario *et al*. found that although the percent CSA stenosis derived from the intracoronary

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guidewire Doppler measurements based on the continuity equation was significantly correlated with the corresponding quantitative angiographic measurements, this determination could be achieved in only 16% of cases.[6] Recently, it has been demonstrated that coronary blood flow velocity can be recorded in the proximal part of the left coronary artery (LCA) with the use of transesophageal Doppler echocardiography (TEDE). In the present study, we tested whether the percent reduction of CSA of the stenosis can be quantitated by TEDE using the continuity equation.

Aim

The purpose of the study was the utility of transesophageal echocardiography in assessing the left main coronary artery (LMCA) stenosis.

MATERIALS AND METHODS

The study was conducted in the Department of Cardiology, Government Rajaji Hospital, Madurai, between January 2009 and April 2010. All patients underwent coronary angiogram and transechocardiography was done and LMCA visualized at midesophageal transverse view at base of the heart and the level of the left sinus of Valsalva and flow was recorded with pulsed wave Doppler.

Study group: A total of 50 patients with an LMCA stenosis were prospectively studied from January 2009 to April 2010. We chose patients with LMCA because TEDE recordings are easier to obtain in these portions of the LCA. A high-quality TEDE signal was obtained in 50 patients (45 men and 5 women, mean age 53 years [range 36–70]). Written informed consent for TEDE examination was obtained in all patients.

Coronary Angiography and Quantitative Coronary Angiography

Coronary angiography was performed using the standard Judkins method with the femoral artery approach. Coronary injections were performed using multiple views, and images were recorded on TOSHIBA flat panel direct digital acquisition system. This quantitative coronary angiographic system has been validated previously. Quantitative analysis of stenosis was performed using the average of results obtained from two orthogonal projections, when available, or the most severe narrowing of several non-orthogonal angiographic projections. Three recognized quantitative variables of stenosis severity were automatically computed by the software: Percent diameter stenosis (DS), minimal lumen diameter, and percent CSA stenosis.

Transesophageal Doppler Echocardiographic Measurements

Transesophageal echocardiography was performed with a 7-MHz probe connected to a Philips IE33 echocardiographic system within 24 h of the angiographic study. A multiplane probe was used in all patients. Transesophageal examination was performed in each patient after oropharyngeal an esthesia by lidocaine. The LMCA was visualized by placing the transducer just above the aortic leaflets. Small adjustments in transducer orientation were necessary to visualize the bifurcation of the vessel into the LAD and circumflex artery. The length and diameter of LMCA (at the level of ostium, shaft, and distal LMCA) were measured. Pre-stenotic and transstenotic coronary flow velocities were then measured as follows: Coronary blood flow was first visualized by color flow imaging and a localized color aliasing phenomenon corresponding to a local flow acceleration was searched; pulsed wave Doppler echocardiography was then sampled in the site immediately upstream from the area of color aliasing; second, the sample volume was moved slightly downward in the area of color aliasing. High pulse repetition frequency or continuous wave Doppler echocardiography was used to quantitate the magnitude of transstenotic velocities if these velocities were too high to be measured by pulsed Doppler echocardiography without aliasing. Small adjustments in the transducer orientation allowed alignment of the ultrasound beam with the long axis of the interrogated proximal portion of the LCA. The peak flow velocity curve was traced from the outer border of the Doppler spectral signal, and the time-velocity integral (TVI) was obtained by planimetry

Table 1: Distribution of age

Age group (in years)	Cases (*n*)%
Up to 40	4 (8)
41–50	16 (32)
51–60	21 (42)
>60	9 (18)
Total	50 (100)
Range	36–70
Mean±SD	53.3±8.1

SD: Standard deviation

Table 2: Distribution of LVID and LVEF

Parameter	Mean±S.D	Range
LVID (D)	5.1±0.67	3.5–7.1
LVID (S)	3.8±0.86	1.9–6
LVEF (T)	46.5±13.9	17–73
LVEF (QLAB)	44.7±11.3	25–73

LVEF: Left ventricular ejection fraction, LVID: Left ventricular internal diameter, SD: Standard deviation

Table 3: Distribution of E/A/DT

Parameter	Mean±S.D	Range
E	64.2±15.4	36–110
A	61±10.9	27–79
DT	139±33.5	56–238

as the area under this peak flow-velocity curve during diastole. Other investigators have previously reported good interobserver and intraobserver reproducibility of coronary flow transesophageal Doppler velocity recording in the proximal part of the LCA 9, 10, 11, 12, 13, 14, 15.

The parameters assessed in T.E.E are as follows:

a. Diameter of LMCA at ostial level, at the level of bifurcation.
b. Length of LMCA.
c. Presence of atheroma.
d. Presence of turbulence.
e. Diastolic flow velocity before the level of stenosis at the level of stenosis and after the level of stenosis.

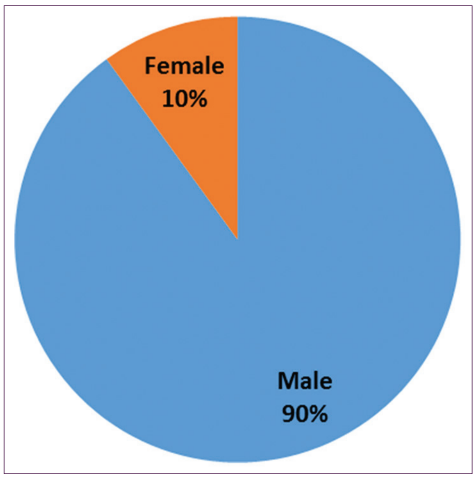

Figure 1: Distribution of gender

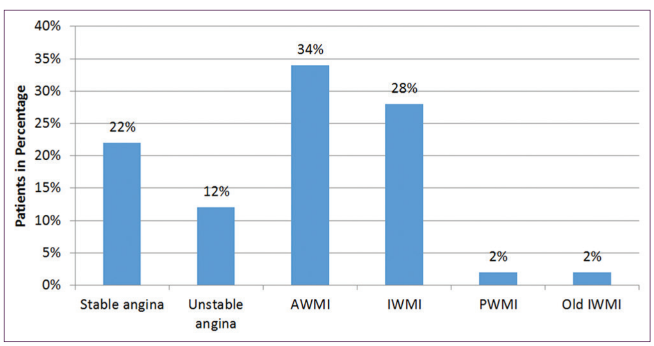

Figure 2: Distribution of diagnosis

f. TVI before the level of stenosis and at the transstenotic level was measured.

RESULTS

A total of 50 patients with an LMCA stenosis were included in the study. 42% of patients were more than 51 years followed by 32% in 41 to 50 years [Table 1]. 90% of patients were male [Figure 1]. AWMI and IWMI were most commonest diagnosis in the study group. Left ventricular internal diameter end diastole and end systole and LV ejection fraction of study patients were distributed in Table 2. E/A ratio and deceleration time of LV were distributed in Table 3.

Coronary Angiographic Data

The length of the LMCA in angiogram varies between 4.5 and 22 mm with a mean of 11.5 and a standard deviation (SD) of 4.2. The diameter of the LMCA at ostial level ranges from 0.96 to 5.31 mm with a mean of 3.28 mm and an SD of 0.84. The diameter of the LMCA at shaft level ranges from 1.4 to 5.03 mm with a mean of 3.04 mm and an SD of 0.89. The diameter of the LMCA at the distal level ranges from 1.11–4.37 mm with a mean of 2.54 mm and an SD of 0.84. The calculated percent DS ranged from 20% to 90% (mean 43.2 and an SD of 15.7) [Table 4].

Transesophageal Doppler Echocardiographic Data

A localized increase in velocity appeared on Doppler color flow mapping as a localized area of aliases, and disturbed signal in all 50 patients studied. In all patients, peak diastolic velocity and diastolic TVI at the pre-stenotic site were obtained by pulsed Doppler echocardiography; transstenotic diastolic peak velocity and TVI were obtained in all patients with the use of either pulsed Doppler echocardiography or high pulse repetition frequency Doppler or continuous wave Doppler echocardiography. The peak diastolic velocity at the stenotic region was 12–103 cm/with a mean of 51.8 and SD of 21.4 and was significantly higher than that measured at the pre-stenotic segment 5–53 cm/with a mean of 25.2 and SD of 11.4. A good linear correlation was found between the

Table 4: Correlation between echo findings and angiogram findings

Parameter	Values as per				Correlation coefficient between echo and angiogram values
	Echo		Angiogram		
	Range	Mean±SD	Range	Mean±SD	
LMCA (L)	3.9–18.8	10±3.2	4.5–22	11.5±4.2	0.7137
Diameter (O)	2–6.9	3.78±1.12	0.96–5.31	3.28±0.84	0.3562
Shaft	1.7–5.2	3.5±0.97	1.4–5.03	3.04±±0.89	0.0267
Bifurca	1.3–6.3	2.99±0.87	1.11–4.37	2.54±0.84	0.3817
% stenosis	12–89	47.8±19.1	20–90	43.2±15.7	0.6007

LMCA: Left main coronary artery, SD: Standard deviation catheterization-derived and TEDE-derived percent CSA stenosis (correlation coefficient of 0.6007) (significant >0.5) and length of the LMCA (correlation coefficient of 0.7137) (significant>0.5). A good linear relationship was also found between the catheterization-derived percent DS and the simple pre-stenotic to stenotic TVI ratio, which was a good discriminator for distinguishing patients with = 50% diameter reduction from those with <50% diameter reduction. All patients with = 50% diameter reduction stenosis at catheterization had a TVI ratio = 0.5 and only four of the 50 patients with <50% diameter reduction had a TVI ratio = 0.5. Thus, ratio = 0.5 predicted = 50% diameter reduction with 90% sensitivity and 85% specificity. The diameter of the coronary vessels did not correlate because the lateral resolution of the two-dimensional sector scan is too low to allow reliable measurements of dimensions of coronary arteries. The present study demonstrates that velocity measurements derived from TEDE can be used for quantitating stenosis of the LMCA [Tables 5 and 6].

DISCUSSION

Use of the Continuity Equation

Based on invasive Doppler measurements have proposed the application of the continuity equation to estimate the severity of coronary stenosis.[4,5,7] However, the methods used in these previously published studies remain invasive requiring cardiac catheterization and cannot be repeated without risk during serial follow-up studies.[4-6] Furthermore, in their consecutive series of 52 patients undergoing percutaneous transluminal coronary angioplasty, Di Mario *et al*. found that, although accurate for quantitation of lesion significance, use of the continuity equation employing intracoronary guide wire Doppler measurements is difficult and impractical for clinical application because high-quality intrastenotic Doppler signals are obtained in only a minority of cases.[6]

In our study, we used a non-invasive approach - TEDE - which can be used more easily in a clinical setting. We found a good linear relation between catheterization-derived and TEDE-derived percent CSA stenosis using the continuity equation. Despite this good linear relation, TEDE measurements significantly underestimated the actual percent CSA stenosis. This discrepancy between transesophageal Doppler measurements and the actual percent CSA may be explained by differences in the cross-sectional velocity profile that may occur between the pre-stenotic and stenotic segment sites. Fluid mechanics theory and previously published experimental studies suggest that cross-sectional velocity profile in a small conduit, like coronary arteries, is parabolic at a low Reynolds number, but flattens when velocities increase, like in stenosis where flow becomes turbulent.[8-12] We have recently confirmed in a clinical study, based on computer analysis of digitally transferred transesophageal color coronary flow maps, that the cross-sectional velocity profile is parabolic in the normal proximal LAD, whereas it becomes flattered when velocities increase like at the site of the stenosis or after intravenous injection of dipyridamole. For clinical purposes, however, the simple TVI ration may be used for predicting with good accuracy the percent DS, which is also a well-recognized variable of stenosis severity.

Clinical Implications

Our data suggest that TEDE allows quantitation of stenosis of the LMCA. This method offers the advantage of a non-invasive technique, which can be applied to many echocardiographic laboratories. Our TEDE method might also represent an adjacent angiography to evaluate mild-to-moderate stenosis. Conventional angiography with visual interpretation, as currently used in many catheterization laboratories, has significant limitations in the assessment of coronary stenosis. In patients with severe coronary diameter reduction on the angiogram, there is usually no difficulty in ascertaining the functional severity of the lesion and in making clinical decisions. In contrast, in some patients with angiographically documented mild-to-moderate stenosis, it is sometimes difficult to evaluate the actual physiologic consequences of the obstruction. Furthermore, contrast angiography, even when using quantitative angiography, is not necessarily suitable for evaluating the results of catheter TEDE measurements using the continuity equation do not rely on any geometric assumption, it might help to confirm the functional severity of stenosis visualized by angiography, especially in cases of mild-to-moderate lesions and after

Table 5: Relationship between pre-/post-TVI stenosis as per angiogram findings

Pre-/post-TVI	Number of cases	% stenosis as per angiogram	
		<50%	≥50%
		n (%)	*n* (%)
<0.5	27	3 (11.1)	24 (88.9)
≥0.5	23	19 (82.6)	4 (17.4)
p		0.0001 Significant	

Table 6: Difference in the values of % stenosis between echo findings and angiogram findings

% stenosis difference between echo findings and angiogram values	Cases
	n (%)
<10%	30 (60)
>10%	20 (40)
Total	50 (100)
Range	–31–(+59)
Mean±SD	4.6±15.8

SD: Standard deviation

catheter-based interventions. TEDE also provides a method for quantitating the severity of the stenosis without inserting any catheter or guide wire into the stenotic segment. In contrast, Doppler catheters or guide wires reduce the actual CSA of the stenosis and may disturb flow field, thus leading to some errors in measurements.

CONCLUSION

Transesophageal Doppler assessment of coronary blood flow is a highly sensitive and specific non-invasive method in the diagnosis of stenotic and occlusive atherosclerosis of the main coronary arteries. A modified continuity equation is hemodynamically correct and allows with the application of transesophageal Doppler allows the accurate calculation of the coronary artery stenosis percentage. The peak diastolic velocity of coronary blood flow (equal to 1.4 ms^{-1} in the LMCA, 0.9 $m.s^{-1}$ in the LAD, and 1.1 $m.s^{-1}$ in the LCX) alongside the aliasing phenomenon is a Doppler criterion of hemodynamically significant stenosis. Break of color mapping absence of Doppler spectrum and registration of retrograde blood flow during late diastole are Doppler echocardiographic criteria for coronary artery occlusion.

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